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Energy efficient houses in Denmark and moisture conditions in highly insulated constructions - rules, practice and education

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Abstract

The Danish Building regulation contains energy requirement for 2010, 2015 and 2020. This will gradually lower the primary energy use in buildings. The rules have maximum allowed U-values and linear heat losses for building parts and maximum allowed transmission heat loss though the opaque part. There are rules for air leakage of the building and the energy balance of the windows. Additionally, there are rules for availability of daylight and indoor climate (thermal and atmospheric). The building must have an energy use below an energy frame that includes heating, ventilation, hot water, electricity for operating the building, solar gains, heat recovery, potential penalty for overheating, etc. A standard calculation method Be10 has to be used. Additionally, a calculation of overheating hours must be done. The real energy use in building is not always as low as calculated with the design rules. The explanation is typically that the inhabitants have a higher indoor temperature or use the building in another way. It is still best to use the design tools to classify energy use and not "real energy consumption". The paper describes literature, measurement and calculation of moisture in highly insulated buildings and concludes that the risk for moisture damage is low for most cases.
Aalborg University and the Danish Building Research Institute has started a 2 year half-time study (Master in Building Physics) for professionals who are responsible for planning, design, construction, operation and maintenance of buildings, and not through their training has achieved the necessary skills in the building physical area. Entry requirement is a master or bachelor degree and at least 2 years working experience in the field. The programme includes theory and practise related to heat, moisture and air, calculation methods for energy and indoor climate and projects for new and refurbished buildings.

1. Introduction

Figure 1. Example of a typical Danish single family house

The Danish Building Regulations has contained energy requirements from 1961. Later changes from 1967, 1972, 1977, 1982, 1985, 1995, 1998, 2008 and 2010 have resulted in a lower energy consumption. In the first periods this was based on giving maximum U-values for the building parts as outer wall, basement wall, floor, roof and window. Since 1977 it has been possible to use a higher U-value in some building parts if others were better thermally insulated. The most recent Building Regulation [1] is from 2010. A new version will come into force from 1. January 2016.

The Danish tradition has been that a ”real” house had an outer wall of bricks and roof tiles, as in figure 1. The size of an average house has increase in time from around 100 m^2 to now 160 m^2.

The EP (Energy Performance) requirements for new buildings were implemented in their current form as the EP calculation method, in 2006, after the implementation of the first European EPBD (Energy Performance of Buildings Directive). These requirements included forecasts for the tightening of the EP requirements in 2010 and 2015 by -approximately 25% compared with the 2006 requirements in each step. In 2009, the requirements were revised [2], and the EP requirements for new buildings were tightened by 25% in the Danish Building Regulations 2010 (BR10)

The existing BR10 sets the minimum energy requirements for all types of new buildings. These requirements relate to the energy frame and the envelope of the building. In addition to the minimum requirements, BR10 also sets the requirements for two voluntary low-energy classes: Low-energy Class 2015 and Building Class 2020. These two classes are expected to be introduced as the minimum requirements by 2015 and 2020, respectively.

2. Energy efficient buildings in Denmark for 2015 and 2020

In the 2010 revision, no forecast for the 2020 EP requirements was included, but the building industry requested this forecast. This led to a process of cost analysis for establishing the different levels of EP requirements. The outcome was the forecast for the EP requirements for new buildings in 2020 - i.e., the Danish NZEB (Near Zero Energy Building) definition. In table 1 is shown the development of residential and non-residential buildings.

Table 1. Primary energy use kWh/m^{2}year for buildings after different rules

	2006	**2010**	**2015**	**2020**
Residential, 150 m^2 heated gross floor area	84.7	63.0	36.7	20.0
Non-residential, 1000 m^2 of heated gross floor area	97.2	73.0	42.0	25.0

The first rules as given in table 2 and 3 gives the maximum requirements for the U-value of building parts and the linear heat loss at some critical places. For instance it is not allowed to use double pane window with clear glass as it would have a U-value of 2.7 W/m^2K. The limit on the linear heat losses makes it necessary to design the house with a limited amount of thermal bridges. The minimum component requirements are primarily intended to eliminate the risk of mould growth due to cold surfaces. It is not possible to construct a building, meeting the energy frame solely by fulfilling the minimum component requirements.

Table 2. Maximum linear heat losses

Linear heat losses	**W/mK**
Between external wall and ground slabs	0.4
Between external wall and windows/doors	0.05
Between roof and windows/doors	0.2

Table 3. Maximum allowed U-values for building parts

Construction	U-value W/m^2K
External wall and basement walls in contact with the soil	0.3
Partition walls and suspended upper floors adjoining rooms/spaces that are unheated or heated to a temperature more than 5 K lower than the temperature in the room/space concerned	0.4
Ground slabs, basement floors in contact with the soil and suspended upper floors above open air or a ventilated crawl space	0.2
Ceiling and roof structures, including jamb walls, flat roofs and sloping walls directly adjoining the roof.	0.2
Windows, including glass walls, roof lights and skylight domes, external doors and hatches to the outside or to rooms/spaces that are unheated or heated to a temperature more than 5 K below the temperature in the room/space concerned	1.8

The Danish Building Regulations also sets requirements for calculating the design transmission heat loss for the building envelope (roof, wall and floor but without windows and doors) for new buildings in table 4. Inside this limit it is allowed to change the U-values of the components if the total frame is kept. It is calculated as an average heat maximum heat flow calculated with the temperature differential indoors-outdoors at 32°C.

Table 4.Maximum allowed transmission heat loss through the opaque part of the building

Rules for year	One floor	Two floors	3 floors or more
2010	5 W/m^2	6 W/m^2	7 W/m^2
2015	4 W/m^2	5 W/m^2	6 W/m^2
2020	3.7 W/m^2	4.7 W/m^2	5.7 W/m^2

The increased requirement for the designed transmission loss of the building envelope excluding windows and doors will increase the thickness of the thermal insulation. Based on economics is it better to increase the insulation thickness in the floor construction and the roof than in the walls. An increase in the insulation thickness in the wall will increase the foot print area (gross area) and give extra cost for materials in the floor and roof. In the rules for calculation of the designed transmission loss it is possible to change the thickness of the thermal insulation in the different parts of the construction, so the “missing” insulation in the walls is put into the floor and roof.

A calculation will explain this: The average heat transfer coefficient U (W/m^2K) of the opaque part of the building envelope:

$$U = Q/ \Delta T$$

Where Q is the transmission heat loss for 2020 buildings 3.7 W/m^2 and ΔT is the temperature difference between indoor 20 C and outdoor -12 C. The average U-value will be (without including the linear heat losses):

$$U_{average} = 3.7/32= 0.116\ W/m^2K$$

I practice the same U-value will not be used in all constructions. A typical Danish outer wall for a 2020 house will consist of (11 cm bricks, 190 mm thermal insulation (mineral wool), 100 mm lightweight concrete + mortar). The U-value in this case will be:

$$U_{wall} = 0.16\ W/m^2K$$

Then the insulation thickness has to be increased in the floor and in the roof. As the wall area (without windows and doors) typically is less than the floor area and the roof area then we can increase the thermal insulation to 400-500 mm mineral wool. The U-value of the roof is then around:

$$U_{roof} = 0.07\text{-}0.08\ W/m^2K$$

This will keep the building inside the rules in the building regulations.

After fulfilling the rules for the average transmission heat loss we are still missing a method that includes the effect of windows, free heat from person and equipment and technical system. This is done by calculating the energy balance for the building.

The energy frame in table 5 is the maximum allowed primary energy demand for a building, including e.g., thermal bridges, solar gains, ventilation, heat recovery, cooling, lighting (non-residential buildings only), boiler and heat pump efficiency, electricity for operating the building, and sanctions for overheating. The calculation method will be discusses in the next section.

Table 5. Energy frame for buildings where A is the heated gross floor area in m^2

Rules for year	**Energy frame for residential buildings [kWh /m² pr. year]**	**Example 160 m^2 single family House**	**Energy frame for non-residential buildings [kWh /m² pr. year]**
2010	52.5 + 1650/A	63	71.3 + 1650/A
2015	30 + 1000/A	36	41 +1000/A
2020	20	20	25

New houses will normally have a heat recovery unit to reduce the heat loss from ventilation. To be sure that we get the heat recovery efficiency in practice the rules include requirements (table 6) for the maximum air-leakage at 50 Pa pressure difference. This is tested with blower door measurements after DS/EN 13829 and the municipalities can require documentation from test of 5% of all new houses and for all houses that comply with the two voluntary low-energy classes. The results of the pressure test must be given as the average of measurements with overpressure and underpressure. The tightness is also important to avoid moisture problems in the constructions.

Table 6.Maximum leakage for buildings of the heated floor area

Rules for year	**Maximal leakage at 50 Pa**	**Maximal opening With area = 160m²**	**Exfiltration**
2010	1.5 l/s pr. m²	21 x 21 cm	0.13 l/s pr. m²
2015	1.0 l/s pr. m²	17 x 17 cm	0.10 l/s pr. m²
2020	0.5 l/s pr. m²	12 x 12 cm	0.07 l/s pr. m²
Passive house	0.4 l/s pr. m²	10.5 x 10.5 cm	0.06 l/s pr. m²

The final missing building component that is important is the window. That is more complicated as we will have a heat loss which is much higher than that of the wall, floor and roof. The window will also have a heat gain from the solar radiation going through the pane. This is positive if it reduce the need for heating but it can also give overheating in the summer. To make a classification of windows we have to take these points into account. This is done by defining an E_{ref} that gives the heat balance for the heating season in kWh/m^2 window area. The value shows the heat balance during the heating season and can be positive or negative. It is calculated for a reference window of 1230 mm times 1480 mm and placed in reference house with half a meter overhang as given in DS418 (Calculation of the heat loss for buildings). The solar gains are calculated as a weighted average for three orientations. The values in the formula are for façade windows. E_{ref} can be used to compare different products and giving energy labels for windows, but not for energy calculations with other window sizes and orientations.

Windows in facade:

$$E_{ref} = 196{,}4 \cdot Gw - 90{,}36 \cdot Uw \text{ [kWh/m² pr. year]}$$

$$Gw = Gg \times Ff \quad \text{or} \quad Gw = Gg \times Ag/Aw$$

Where Gw = Window total solar transmittance
Uw = Total U-value of window
Gg = Solar transmittance of glass
Ag = Glass area
Aw = Total area of window
Ff = Glasspart (Ag/Aw)

In table 7 are the rules for the window types that can be used in the different building types. It is seen that from 2020 only windows that is classified as A can be used.

Table 7. Energy balance and labels for windows in facades.

Year	Energy balance (E_{ref}) Windows in facade	Windows Energy labels
2010	> -33 kWh/m² year	A or B or C
2015	> -17 kWh/m² year	A or B
2020	> 0 kWh/m² year	A

Before we make the energy calculations it is necessary to take a look on the technical installations as they will influence the result. An important barrier to achieve good results, come from the dry heat recovery efficiency of the HRV (Heat Recovery and Ventilation) systems. In the Danish and European market the efficiency quite low, with typical values of around 70-75%, while the electricity use at the same time is quite high, so it is difficult for most HRV systems to live up to SEL (Specific Electricity Use) values of less than 1200 J/m^3 in electricity use for individual systems and 2100 J/m^3 for larger common systems.

The rules in the Building Regulations are given in table 8 and below:

- Heat recovery with minimum 70% efficiency

- Heat Pump COP (Coefficient of Performance) minimum norm effect factor at least 3.6 for air/air systems. For air/water heat pumps for water based heating in the floor heating or in a radiator system can the value be lower.

Table 8. Maximum specific electricity use for ventilation systems

	Maximal SEL-value J/m^3
Mechanical exhaustion	800
Mechanical ventilation in single flat	1000
CAV (constant air volume)	1800
VAV (variable air volume)	2100

3. Calculation of energy use and indoor climate

To check that the building is inside the energy frame the building authorities has decided that a special program Be10 shall be used. This is described in the SBi direction 213[3]: Energy demand in buildings (In Danish). The procedure follows the relevant CEN standards to great extent. This publication also includes the updated PC calculation program Be10. The calculation core of this program is to be used by all other programs for compliance checks and energy certification, to ensure the identical calculation of the energy performance of buildings. It is based on calculations based on monthly values of temperature and solar radiation. Figure 2 shows the screen from the program. At the left is overview of all parts of the building and its technical installations. This includes areas, U-values, windows, ventilation, hot water, persons, heat recovery, solar panels etc. If we click on a symbol on the left a page opens to the right. Here all the necessary data is written. When all data has been given we can ask for a calculation. The right part of figure 2 shows results of the calculation compared with the energy frame for the different years.

The program calculates the energy that is needed for heating, ventilation, cooling, hot water and lights as

Heat demand x EF + Electricity x EF – Renewable Energy + Overheating Penalty < Energy Frame

The energy frame is from table 5. EF is an primary energy factor depending on the type of energy used. The values are politically motivated as for instance electricity is 2.5 as Denmark do not have hydro power and district heating is 1.0. The factor for gas is 1.0. Oil heating is going to end in a few years and not allowed for new houses. For 2015 is EF for district heating 0.8 and for 2.5 for electricity. For 2020 is EF for district heating 0.6 and 1.8 for electricity. District heating is the most favourable. The lower value for electricity in 2020 is due to increased use of wind power in the production of electricity.

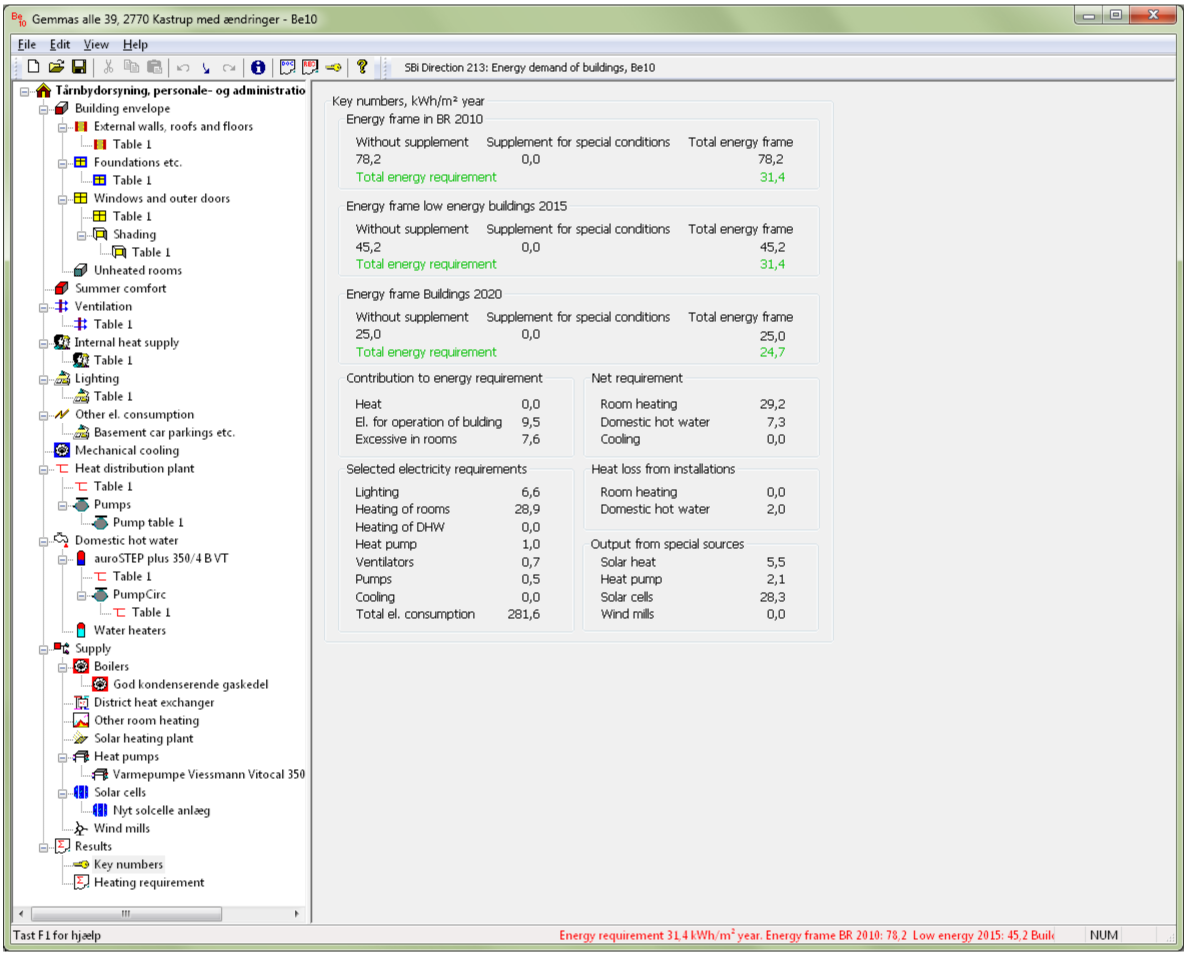

Figure 2. View of screen from Be10 energy calculation program.

Experience from first generation Danish homes built as low-energy buildings have shown that sometimes there will be problems with overheating. This is typically caused by large windows facing south, east and west, with a lack of shading and limited opportunity for ventilation. To increase focus on this problem compliance with low energy class 2015 and the class of 2020 will require a calculation of the thermal indoor climate. The rules are given in table 9 for the new 2015 climate data. The temperature must not exceed 27 ° C for more than 100 hours pr. year and 28 ° C for more than 25 hours pr. year. The calculation must be done on the worst room in the building.

Table 9. Overheating hours pr. year

Year	**Number of hours above 27 °C**	**Number of hours above 28 °C**
2010	**No rules**	**No rules**
2015	**< 100**	**< 25**
2020	**< 100**	**< 25**

The rules for proof of the calculated thermal indoor climate on sunny days should relieve the problem of high temperatures. Since it is often difficult and expensive to remedy overheating in housing and office buildings when the building first built, it is vital that there is focus on the problem with overheating at the design stage.

The possibility of active use of natural ventilation should be included. Swedish experience from 10 years old passive houses show that in these houses have proved to work well with venting excess heat in the summer. In particular skylights have been found effective. It was also a desirable solutions that make it possible to ventilate naturally when the house is unoccupied or at night. Such ventilation systems should be incorporated right from the design stage, if they do not provide new problems such as intrusion and rainfall.

Another solution to prevent overheating is the use of solar protection. When selecting sun protection, there is great variation in the type and technology, but the best types is that the shield should be exterior and mobile, as this provides the most effective solution. Interior solutions can protect people against direct solar radiation, but not the heat from entering the building and can cause problems with overheating.

Solar control glass is a third option, but thereby cut off both light and heat also at times when the light and heat of the sun could be recovered. Not a good solution in residential buildings.

Much can be done in the early design phase with good new windows, energy consumption increased only slightly by orienting a greater part of the windows, for example, to the north, so that a better distribution of windows after orientation can have a beneficial impact on the indoor environment both for better daylighting and thermal climate.

In design of more complicated buildings and for more accurate calculation of energy use and indoor climate can it be necessary to use more advanced method than Be10 as e.g. BSim (Building Simulation) [4] that calculated on hourly basis. Then it is easier to predict the indoor temperatures in the summer and evaluate methods to reduce them.

The Danish Building Research Institute has made a study [5] on new Danish detached low-energy single-family houses to identify possible problems the owner’s satisfaction. “A questionnaire survey was carried out in the autumn of 2013 among owners of newly built low-energy class 2015 houses. It included questions on their overall satisfaction, and more specifically their satisfaction with the indoor climate (temperature, draught, air quality, noise and daylight), and their experience with technical installations and heat consumption. The questionnaire was answered by 370 of 869 house owners corresponding to a response rate of 43%. The survey showed an overall satisfaction with the new low-energy houses, as 93% of the house owners would recommend living in such houses to others. The high rate of satisfaction may, among other things, be due to the fact that more than 90% of the house owners perceived the indoor environment as satisfactory both in summer and winter. The energy consumption was found to be as low as expected by 59%, while only 7% answered that it was higher than expected. Compared with previous similar studies, problems with technical installations and design have decreased. However, there is a need for continued focus on the commissioning of new, and not necessarily thoroughly tested, high-performance installations and new designs to achieve both low energy consumption and satisfied house owners.”

4. Difference between calculated and later measured energy consumption

In practice the energy consumption is not the same as calculated with the standard method. In most cases the energy consumption is higher. The first problem with comparing is that in most buildings is it not possibly to measure all the energy used in detail. The electricity is typically measured but that only gives the total use. So it is possible to see that it is higher than expected. Sometimes you measure the hot water used and that can show if the use is higher than normal.

The data program Be10, that is used to show if the building project comply with the requirement in the energy frame, can also be used to make energy calculations with other conditions than the standard assumptions. The standard conditions should be for a standard family, but as all families are different will we always get differences. Some of these can be tested with making calculations for the house as a change in indoor temperature from 20 °C to 22 °C. Most people will prefer 22 °C.

A first difference can come from a 2 °C higher indoor temperature in a typical single family house gives increased energy consumption of approx. 16 % under Danish climate conditions.

A second difference can be that the family has fewer persons, or the family is less at home than expected, so the heat from persons is 0.75 W/m^2 instead of the standard 1.5 W/m^2 from the design.

A third difference can be the "free heat" from lightning, washing machines, freezers and coolers and other electric appliances in the building. Here is expected an average heat load of 3.5 W/m^2, but kitchen use, TV and gaming and the amount of equipment can be different. Has the family less electric equipment and use it less then can the heat load be 5 W/m^2 instead of 3.5 W/m^2 for persons and equipment and can give an increase in heating.

A fourth difference is the air change of the building. That is difficult to measure but a higher leakage in the constructions will increase the energy use.

4.1 Energy use in Danish buildings

An investigation in the energy use in the Danish building stock can give interesting information.

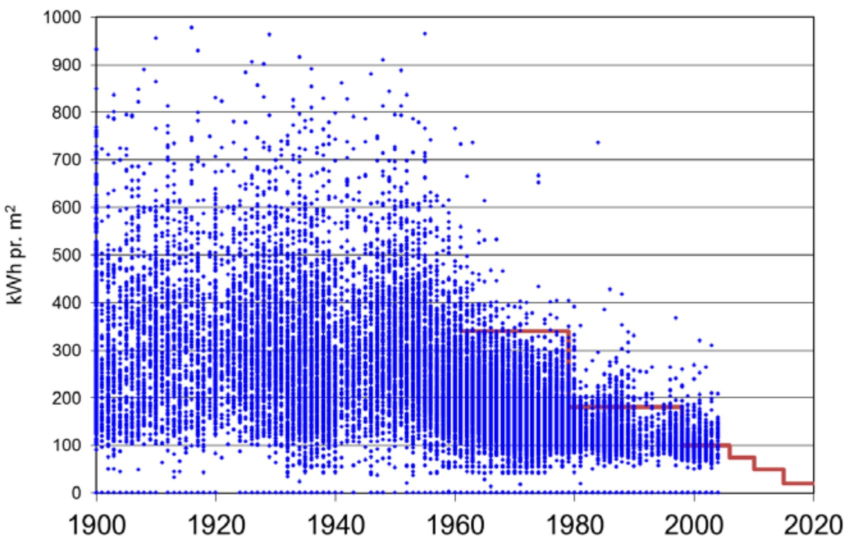

Figure 3. Measured energy consumption (dots) in Danish houses for different construction year. The thick line is the requirement in the Danish Building Regulations.

Figure 3 shows measured energy consumption for houses in relation to construction year [6]. The horizontal line with steps is the level of the rules in the Danish Building Regulations from 1961 and onwards. It is seen that for most houses from 1960 to 1996, the energy consumption is below the requirement level. After 1996 more houses have a higher energy use than the Danish Building Regulations probably because most people will have a slightly higher indoor temperature that only give a small increase in the energy bill. The new Building Regulation will lower the expected energy consumption as seen but we will still have variations from the inhabitants and their behaviour.

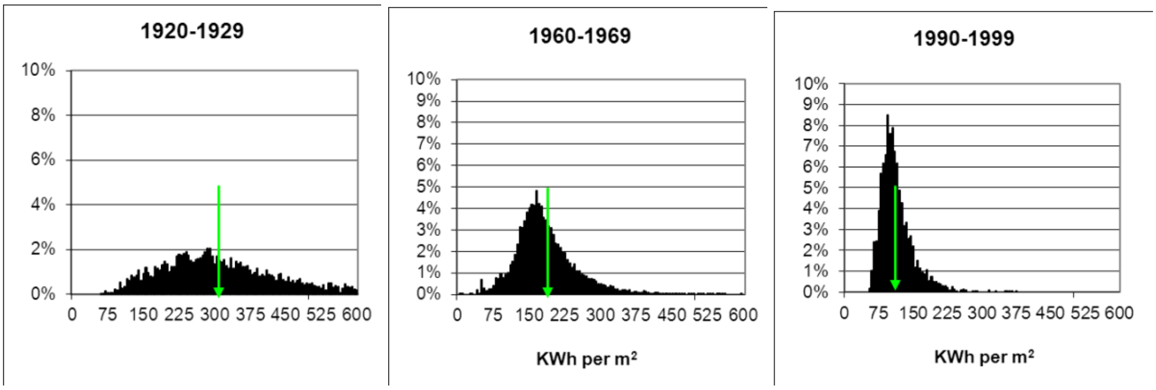

Figure 4. Variation in energy demand of houses with different construction year.

Figure 4 shows that old houses have a high energy demand and large variation and new houses has lower energy demand and less absolute variation [6]. The arrows indicate the average values. The results show that newer house has less variation than old houses. A calculation based on the theoretical value will therefore be more correct for new houses.

4.2 Real variation in energy use

A number of research projects as [7] and [8] has shown that the there is a large variation in how different families live and how much energy they use. Some groups will try to save energy and follow the consumption; others do not think this is important. So in a group of equal houses or flats there will be variations mostly based on the users. A Swedish project [7] has looked at measurements of energy consumption for 38 individual single-family houses over a period of 10 years.

The result show that the energy use change from year to year as for instance a new baby increase the energy use and teenagers leaving the family decrease the energy use. Also a new hobby or change in work can have effect. It is also seen that a new family moving in will have a different behaviour and another energy use.

A Norwegian investigation [8] has looked on the uncertainty in the energy consumption for a typical house if we take into account that we will always have variations from the outdoor climate, the building and the user's behaviour. The variations for the parameters were estimated based on typical variation of for instance the indoor temperature etc. The result of the simulations is seen in figure 5. The variation in the energy use is similar to measured variations for number of identical houses or flats.

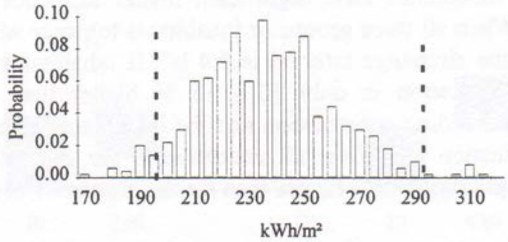

Figure 5. Results from 500 cases with variations from climate, building and inhabitants.

As this is a simulation we can find out which parameters have most influence on the variations (standard deviations). Figure 6 show the standard deviation from the outdoor climate (C), building (B) and the inhabitants (I) and combinations of them. It is seen of the three parameters will the inhabitants give the largest variations. And also the variation from climate and building (CB) is much less the influence from the inhabitants (I). A classification of the buildings energy use should therefore try to avoid the influence from the inhabitants.

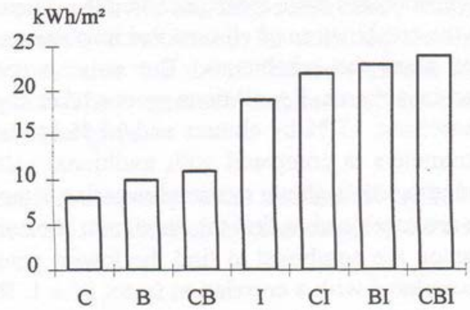

Figure 6. Standard deviation from simulations with variables from the group climate (C), building (B) and inhabitants (I) alone and together. The letter below each column indicate the combination of group.

It has been argued that the Danish design tool is not good as the real energy consumption in the house is different from the measured, and it is better to give the real consumption. This is done in Sweden for classification, but then it is a measure that not only give information on the buildings thermal behaviour but also the number of inhabitants and their individual behaviour and the climate in the year where the measurements are done.

4.3 Blocks of flats

For blocks of flats, it is interesting to know not only the energy demand of the entire building, but also the energy demand of each flat. It is typical that flats immediately below the roof, above an unheated basement and at the building ends have a higher energy demand. This is the effect of different heat losses, but another factor also has an impact. That is the indoor temperature. A lower indoor temperature results in energy savings that are very economic as it does not cost any money. If we calculate with Danish climate conditions, a lowering of the temperature by 2 °C will result in a 20 % energy saving or 10% per °C for heating.

If we lower the temperature by 2 C in all flats in the block, we get the 20 % energy saving. But that is not the case when we consider lowering the temperature in an individual flat. Here, a lowering of the temperature gives a much higher energy saving as you receive heat from your neighbours if they do not lower their temperature. It is important to be aware of this effect if you make individual measurements of the heating demand and perform calculations of the expected heating bill. It is normal in Denmark to have a central heating system and each flat pays part of the total heating bill of the building. Typically this is based on measuring the indoor temperature or the heating consumption of each flat.

A calculation of savings for single flats in building from different building years is done in [9], where the building and the exact results are given. The savings of two-room flats were:

- Top floor (under the roof) approx. 30%
- Between floors approx. 45%
- Lower floor (against basement) approx. 30%

As a result of these savings, the energy consumption of the adjoining flats increases by up to 11%. The adjoining flats will probably not be aware of it as variations from the inhabitants and their behaviour can be of the same size. The building's total energy consumption is almost unaffected by individual flats lowering temperature. This problem will continue to exist also in new buildings as we do only have limited thermal (primarily due to noise insulation) insulation between flats.

5. New constructions and moisture problems?

The rules for new building in 2020 will result in new constructions with increased insulation thickness. It is important find out if this gives moisture problems in the construction. The Danish Building Research Institute has a project related to this problem. It includes literature study, theoretical calculations and measurement on some houses. This is done for typical constructions in Denmark. Similar studies have been done in Sweden and Norway.

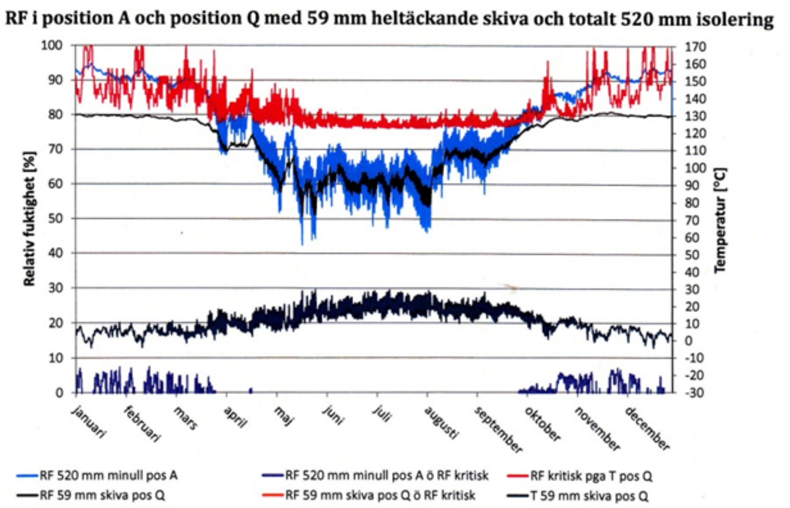

Diagram 42. RF i position Q (svart), RF i position A (turkos), RF_{krit} (röd), temperatur (mörkblå), RF position Q över RF_{krit} (ljusbrun), RF position A över RF_{krit} (lila).

Figure 7. Swedish Calculation of temperature, RH and mould risk

For a wall construction thicker insulation will make the outer part colder and increase the relative humidity in that part. A wooden outer panel will be more wet and the risk of mould grow will increase. In figure 7 is an example of a Swedish wooden wall with 520 mm mineral wool [10]. In the lower part of the figure is seen when we have a risk for mould growth from November to March. With a lower insulation thickness the risk is less. In Denmark a wall will probably not get as thick as we will have bricks outside. For a brick wall we typically have a partly ventilated gap and the insulation thickness is around 2-300 mm mineral wool, so it will also give a lower brick temperature. If we have building moisture or moisture from a leakage then it will take longer time to dry out.

For a ventilated roof is the interesting information the temperature and the relative humidity. The air temperature in the attic will not change very much if we increase the insulation thickness. For Denmark it can be 2 °C colder in the winter and the same temperature in the summer with an increase from 100 mm to 500 mm. In figure 8 is a Norwegian calculation [11] for a ventilated roof with different insulation thicknesses from 100 mm to 750 mm. The relative humidity increase from 100 mm to 250 mm but not very much from 250 mm to 750 mm. In this calculation the vapour barrier is tight as we also expect in practise.

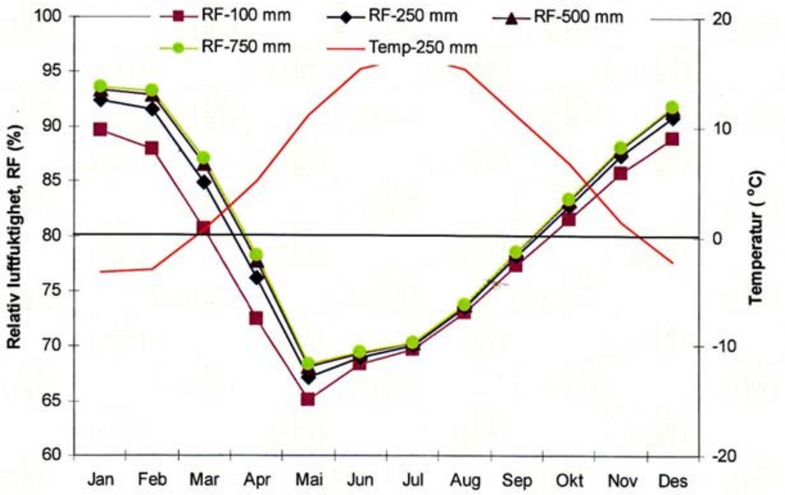

Figure 8. Norwegian calculation of temperature and RH in a roof

We will get increased problems in ventilated crawl spaces if we increase the insulation in the floor above the crawl space. But the construction had problems also with todays insulation levels. It must be avoided in highly insulated buildings.

The general result for walls and roofs is that there will be a slight increace in relartive humity in the outer part of the construction. As the drying out will be slower it will be more important to keep the moisture out the constructions in the building periods As always thing can go wrong if the constuction is poorly designed or buildt. Vapour barriers must be tight. SBi has moisture guidelines [12], that is use to design good construction related to moisture. Small revisions can come but we do not expect major revision from building highly insulated buildings

6. Education: Master in Building Physics

The Danish Building Research Institute at Aalborg University stated in 2013 a master education in Building Physics [13]. This is a part-time course that finishes at the graduate level. The most well-known education of this type is Master in Business Administration (MBA). Participants who do not have a prior master's degree may via a master's degree obtain a formal competence level. Participants who already have a Master's degree may use participation in postgraduate study as updating and training. The background is that we need to reduce the energy consumption in the existing building stock and that many building damages come from moisture. A better moisture design is much needed. Before there was no accredited continuing education in building physics but only short courses. Master in Building Physics is an accredited education (approved by the ministry) that provides formal qualifications. The program is research based, which among other things means that the student meets the leading experts in the field and learns to use current research theories and methods. Most of the teachers come from the SBi and are also involved in writing Directions for the Danish Regulations and many SBi Directions are used in the building sector.

The competence level, master degree program in Building Physics will give is particularly aimed at the professionals who are responsible for planning, design, construction, operation and maintenance of buildings. Many persons have not through their training achieved the necessary skills in the building physical area, regardless that their work requires building physical insight. These groups include building designers and architects, but also some groups of engineers.

The education is a 2 year education which gives 60 ECTS point as it is a halftime study. The student will normally have a job in a firm beside the study. They will pay the costs that are 3200 € pr. semester or total 12800 € for the whole education.

Entry requirements for the study are:

- Master of Science in Engineering (building technology)
- Bachelor of Engineering (building technology)
- Bachelor in Architectural Technology and Construction Management.
- Architect (Building technology)

Additional requirements is at least two years of relevant work experience in construction and building technology at a high level as working as an engineer or architect.

Table 10. Courses in Master in Building Physics

Semester	Course	ECTS
1. 15 ECTS	Heat Theory and Practice	5
	Moisture Theory and Practice	5
	Air Tightness and Ventilation	5
2. 15 ECTS	Indoor and Outdoor Climate	5
	Energy, Heat and Moisture Calculation Methods	10
3. 15 ECTS	Condition Assessment, Re-insulation and Refurbishment	10
	New Buildings – New Materials and Solutions in Building Technology	5
4. 15 ECTS	Master's Thesis	15

The courses are seen in table 10. All are given in Danish. The first semester gives the theoretical background for heat, moisture and air tightness and includes discussion of the practical aspects of the theory. The second semester includes indoor and outdoor climate and calculation methods for energy, indoor climate, heat and moisture. The programs are the one typically used in the building sector in Denmark, Be10 [3], BSim [4], Heat2 and WUFI. The third semester is the use of the theory and calculations on real buildings. One course is for new buildings and the other for refurbishment, re-insulation for the existing building. The fourth semester is the final theses work that can typically be related to a project or problem that the students firm is interested in.

The education is in each semester done in 3 weeks and then an examination as in table 11. The concentration of the education in 3 weeks makes it possible to participate from all parts of Denmark. Each education week (example table 12) is packed with lectures, so the participant has to be present. Between the education weeks there are tasks that must be done to next period. The tasks are normally done in groups of 2-3 students.

Table 11. Semester program for first semester

September	October	November	December	January
36	41	45	49 3 week	1
37 1. week	42	46	50	2 examination
38	43	47	51	
39	44 2 week	48	52	
40			53	

Table 12. Week program for first semester

Week 37	Monday 9. Sep.	Tuesday 10. Sep.	Wednesday 11. Sep.	Thursday 12. Sep.	Friday 13. Sep.
08.15 - 12.00	Heat theory and practice	Heat theory and practice	Moisture theory and practice	Air tightness and ventilation	Air tightness and ventilation
	Lunch	Lunch	Lunch	Lunch	
12.45 - 16.30	Heat theory and practice	Moisture theory and practice	Moisture theory and practice	Air tightness and ventilation	

The first group finished the thesis works in June 2015 with good result. We have got a positive feed-back from the students.

7. Summary

The Danish building regulations has not only rules for energy efficient houses that shall be used today but also rules for future. The advantage is that the building industry has time to adapt and it is possible to build very energy efficient houses complying with the future rules. The rules make it necessary to use a program as Be10 for making the energy design. The new rules also include that overheating must be calculated. The real energy use in building is not always as low as calculated with the design rules. The explanation is typically the inhabitant that for instance have a higher indoor temperature or use the house in another way that given in the design tool. It is still best to use the standard design tools to classify energy use and not “real energy consumption”. The new buildings have thicker insulation that could give moisture problems due to less heat flow through the construction. Calculations and measurement show that in most cases the risk is low if you still build after the moisture guidelines. At the end is a description of a new Danish part-time education in energy savings and moisture design.

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